A Geographic Information Systems approach for classifying and mapping forest management category in Baihe Forestry Bureau, Northeast China

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Abstract: This paper demonstrates a Geographic Information Systems (GIS) procedure of classifying and mapping forest management category in Baihe Forestry Burea, Jilin Province, China. Within the study area, Baihe Forestry Bureau land was classified into a two-hierarchy system. The top-level class included the non-forest and forest. Over 96% of land area is forest in the study area, which was further divided into key ecological service forest (KES), general ecological service forest (GES), and commodity forest (COM). COM covered 45.0% of the total land area and was the major forest management type in Baihe Forest Bureau. KES and GES accounted for 21.2% and 29.9% of the total land area, respectively. The forest management zones designed with GIS in this study were then compared with the forest management zones established using the hand draw by the local agency. There were obvious differences between the two products. It suggested that the differences had some to do with the data sources, basic unit and mapping procedures. It also suggested that the GIS method was a useful tool in integrating forest inventory data and other data for classifying and mapping forest zones to meet the needs of the classified forest management system.

Keywords: Classified forest management; Key ecological service forest; GIS; Baihe Forestry Bureau

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Introduction

Forest ecosystems provide wood products and a wide range of valuable services, including soil/water protection, biodiversity conservation, and carbon sequestration (Costanza *et al.* 1997; Ouyang *et al.* 1999). Due to the fast growing of human population, forests have been excessively harvested, the quality of the remaining forests has been degraded and ecological functions of the forests have been weakened. This directly or indirectly threatens the quality of human life in many places of the world. Many scholars have addressed the non-productive functions of forest ecosystems (Ian *et al*. 1997; Ozanne *et al.* 2003). An effective way to balance between productive and non-productive functions of forest ecosystems is to apply classified forest management, which has been widely accepted and used over the world (Lamas *et al*. 1995; Larsen *et al.* 2000). For example, the non-productive forest reaches to 33.5% of the total forests in area in the US in 1992 (Liang *et al.* 2001). The classified forest management is so effective that the non-productive forests reach to 82% of the total forests in area in New Zealand (Liang *et al.* 2001). A number of countries in the Asia-Pacific region such as New Zealand, Sri Lanka, Thailand, and Viet Nam have imposed partial or total logging bans (or similar restrictions on timber harvesting) in response to rapid deforestation and degradation of natural forests (Durst *et al*. 2001).

In China, the concepts of sustainable forest management and forest services have been increasingly more recognized (Zhang *et al.* 2000; Xu *et al.* 2000; Zhou 2002). The original forest classification system became part of the forest law in China in 1979 and 1984, in which forests are divided into five categories: Protection Forest, Timber Forest, Economic Forest, Energy Forest and Special-Purpose Forest. The protection of natural forest in national key forest zone was declared in 1998. The criteria of designing key ecological service forest were released in 2004. Classifying and mapping forest management category have been employed in countrywide forestry areas.

Geographic information systems (GIS) are useful tools for land classifications (Shao *et al.* 1996; Silviro *et al.* 2005). In the process of classified forest management, classifying forest is an essential step. The methods of classifying forest have been discussed by several researches (Wang *et al.* 2000; Hong and Cai 2002; Mark *et al.* 2004). However, most of the studies are basically depended on the traditional forest inventory data and manual procedures. The paper introduces a GIS approach to classify and map forest management category and compares the map product with the existing product developed with the traditional forest inventory data and manual procedures.

Materials and methods

Study area

The study area, Baihe Forestry Bureau in Jilin Province, is located next to Changbai Mountain Nature Reserve on the north-facing slope of Changbai Mountain with a total area of 190,000 hm^2 (127°53′ and 128°34′ E, and 42°01′ and 42°48′N). There are 10 forest farms, 995 compartments, and 13 777 sub-compartments in Baihe Forestry Bureau. The climate in the study area is characterized by cold winters and cool and humid summers. The average annual temperature is 2.2 °C; frost-free

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period lasts 110 days and average annual precipitation is 700−1100 mm. The average elevation is 800 m and the average slope is about 5 degrees.

Classifying and mapping forest management category

According to the classification principle established by the State Forestry Administration, this study considered the slope as an important factor in classifying forestland in the mountainous terrains because topographic conditions are directly related to hydrological functions of forests (ECOMAP 1993) and determines the ecological land types (Dai *et al.* 2003). The special purpose forest including the seed tree forest, natural reserve, defense forest and so on is important to sustain and preserve the ecosystem. The broadleaved/Korean pine forest is native vegetation and provides rich species and important habitats for many endangered wildlife. However, this old-growth forest only existed in natural reserve and some remote areas because of 4 decades of extensive forest cutting (Shao *et al.* 1996). The ecotone sometimes holds more species and belongs to ecological sensitive zone (Nobel 1993; Wang *et al.* 1997). From these points of view, this study also considered the special use forest, broadleaved/Korean pine forest and ecotone as a major factor in the classification. In summary, the major principle or criteria applied to classify forest zones was as follows:

A. Forestland (FL) (including 3 management types):

a. Key ecological service forest (KES): Slope≥30°or the broadleaved/Korean pine forest or distance ≤250 m to river or special use forest or distance ≤10 km to the frontier between China and North Korea

b. Commodity forest (COM): Slope≤15°and distance ≥100m to road and distance ≥50m to non-forest land.

c. General ecological service forest (GES): None of above.

B. Non-forestland (NFL): Residential area, farmland, and so on.

A GIS data layer was developed by digitizing forest inventory maps and joined with attribute data collected in sample points within every sub-compartment on the ground in 2000. The FL and NFL were categorized according to land use type in the attribute table.

A digital elevation model (DEM) with a scale of 1:100,000 and a spatial resolution of 25 m was used to calculate slope percent, and slopes were classified into three levels: Slope I ≥ 30°, 15° <Slope II < 30°, and Slope III ≤ 15°. The slope grid was vectorized and the vector slope data layer was then overlaid with the forest inventory GIS data layer.

Rivers and roads were extracted from Landsat TM with EDARS 8.6. Sub-compartments located within 250 m in distance to rivers were selected with ArcMap in two steps. The first step was to obtain 250-m-wide buffer zone of rivers in the Buffer Wizard; the second step was to intersect the buffer zone with the forest inventory data layer in the Geoprocessing Wizard of ArcMap. All sub-compartments located within 100 m in distance to roads or within 50 m in distance to NFL and 10 km in distance to the frontier were selected with the same two-step method. The special purpose forest was defined based on forest use category in the attribute table. Any sub-compartment that contained Korean pine as dominant tree species was considered as broadleaved/Korean pine forest. The new information was joined to the attribute table associated with the forest inventory data layer.

The landscape indices such as patch number, mean patch area and so on were useful tools to characterize the difference between two landscapes, so they were computed in FRAGSTATS 3.3 with 25-m cell as the basic unit for the manually made and GIS classifying forest zones.

Results

The manually made forest zones

Forest zones in Baihe Forestry Bureau were manually classified by using the forest inventory data with compartment as a basic unit in 2000. The characteristics of each forest type were summarized in Table 1. The land was classified into three types: KES, GES, and COM. NFL was not considered. GES contained 419 compartments, covered 41.81% of the total area, and KES and COM accounted for 26.2% and 26.4% of the total area, respectively. There were so many compartments that two compartments were excluded. GES was the major component in the manually made forest zones.

Table 1. Landscape of the manually made forest management types classified by the local Forestry Bureau

Landscape indices	Excluded area	KES	GES	COM	Total
Compartment	2	311	419	263	995
Sub-compartment	31	4 305	5,665	3776	13 777
Patch number	2	8	19	8	37
Patch area (hm^2)	356.5	60 038.4	79 407.3	50 144.6	189 946.8
Mean patch area (hm^2)	178.3	7 504.8	4 179.3	6 268.1	5 133.7
Percent total area (%)	0.2	26.2	41.8	26.4	100

Notes: KES--- Key ecological service forest, GES--- General ecological service forest, COM--- Commodity forest.

The top-level classification

A total of 7 408.8 hm^2 of the land or 886 sub-compartments were classified as NFL, which accounted for only 3.9% of the total area (Table 2). Farmland was the major component in NFL, accounting for 80.78% of NFL in area. FL was composed of 12 891 sub-compartments with 182 538 hm^2 in area in Baihe Forestry Bureau. There were 55 forest patches and the mean patch area was 3 318.9 hm^2.

The total lengths of rivers and roads in Baihe Forestry Bureau were 245 and 468 km, respectively. Rivers and roads were often used as the boundary between compartments. The sub-compartments in the forestland intercepted by a 100-m buffer zone of each river and a 250-m buffer of each road accounted for 2 075 and 1 106 in number, and 305 387 hm^2 and 192 224 hm^2 in total area, respectively.

The broadleaved/Korean pine forest was found only in 70 sub-compartments with a total area of 1 093.4 hm^2. The forests for special purpose were composed of the defense forest in-

cluding 109 sub-compartments with a total area of 3 343.8 hm^2, the seed tree forest including 145 sub-compartments with a total area of 3 456.1 hm^2, and natural reserve including 53 sub-compartments with a total area of 1 005.7 hm^2.

Baihe Forestry Bureau mainly featured with flat land and gentle slopes. Only 24.7 hm^2 of the land was with slope≥30°, accounting for 0.013% of the total area, and 97.68% of the total area was with slope≤15°. Based on the sub-compartment, 987.94 hm^2 of the forestland with slope ≥30° including 37 sub-compartments was accounted for 0.54% of the forestland and 85.16% of the forestland including 11 490 sub-compartments was with slope≤15°.

There were 1 841 sub-compartments accounting for 13.95% of the forestland within a distance of 50 m around the non-forest land. There were 972 sub-compartments within a distance of 10 km to the frontier, which accounted for 9.08% of the forestland.

Table 2. Forest landscape of the forest and non-forest lands classified with GIS based on the sub-compartment

Landscape indices	Farm land	Residential area	NFL	FL
Sub-compartment	742	69	886	12891
Patch number	543	48	577	55
Patch area (hm^2)	5984.8	1174.4	7408.8	182538
Mean patch area (hm^2)	11.0	24.5	12.8	3318.9

Notes: NFL--- Non-forestland, FL--- Forestland.

The general factors and their role in the forestland

The re-classified forest management types in the forestland by GIS

The re-classified forest management types were indicated in Table 3. The forestland in Baihe Forestry Bureau was re-classified into three types: KES, GES, and COM. COM including 6 833 sub-compartments was the main body and accounted for 45.0% of the total area. KES reached 40 356.5 hm^{2}and its mean area was 377.2 hm^2. GES including 3 799 sub-compartments was accounted for 29.9% of the total area. The patch number in total reached 1 420 and was 38 times bigger than those of the forest management types classified by the local Forestry Bureau.

Table 3. Landscape of the re-classified forest management types based on the sub-compartment with GIS

Landscape indices	NFL	KES	GES	COM	Total
Sub-compartment	886	2259	3799	6833	13777
Patch number	575	107	154	584	1,420
Patch area (hm^2)	7408.8	40356.5	56701.6	85479.9	189946.8
Mean patch area (hm^2)	12.9	377.2	368.2	146.4	132.6
Percent total area	3.9	21.2	29.9	45.0	100

Notes: NFL--- Non-forestland, KES--- Key ecological service forest, GES--- General ecological service forest, COM--- Commodity forest.

The comparison between the classified and re-classified system

The differences between the classified system by the local Forestry Bureau and the re-classified system in this study were examined using transformation matrix (Table 4 and Fig. 1).The ratios of no transfer to COM, GES and KES all exceeded 25%. The ratio of no transfer to COM reached 56.4% and was the biggest in those. The transfer area from COM to GES and KES were 20 281.8 hm^2 and 1 071.3 hm^2, respectively.

The transfer area from GES to COM was 40,469.2 hm^{2}and from GES to KES was 1 2 181.7 hm^2. The transfer area from KES to COM was 27 933.6 hm^{2}and from KES to GES was 12 773.4 hm^2. The total area of COM in the re-classified forest management types increased and the total areas of GES and KES decreased.

Table 4. Area transformations from the manually made classified system (CS) to re-classified system based on the GIS (RCS)

CS	NFL	COM	GES	KES	Total
NZ	7.6(2.1)	57.2(16.0)	291.7(81.8)	0	356.5
COM	507.1 (1.0)	28284.4(56.4)	20281.8 (40.4)	1071.3(2.1)	50144.6
GES	2727.0(3.4)	40469.2(51.0)	24029.4(30.3)	12181.7(15.3)	79407.3
KES	4167.1(6.9)	27933.6(46.5)	12773.4(21.3)	15164.3(25.3)	60038.4
Total	7408.8	96744.4	57376.2	28417.4	189946.8

Notes: The unit is hm^2; the number in the blanket is the percent; NZ shows the two excluded compartments in the manually made classified system; CS--- The manually made classified system, RCS--- Re-classified classified system based on GIS, KES- Key ecological service forest, GES--- General ecological service forest, COM--- Commodity forest.

Discussion

In the re-classification, the land was firstly divided into two groups: the forestland (FL) and the non-forest land (NFL), then the forestland was further classified into COM, GES, and, KES, respectively. A two-hierarchy system was applied in the re-classification system and changed the one-hierarchy system established by the local Forestry Bureau. The non-forest land only accounted for 3.90% of the total area and mainly consisted of the farmland and residential area because Baihe Forestry Bureau was located in the Northeast Forest Zone, where population was not so dense and over 40% of inhabitants engaged in forestry activities.

There was an obvious difference between the classification established by the local agency and the re-classification in this study. The non-productive forest types including GES and KES were the main body in two Forestry's classification systems while the area of COM intensely increased in the re-classification system. The difference was related with the basic unit, data, method and so on. The compartment was used as the basic unit in the classification established by the local agency; however, the sub-compartment was used as the basic unit in the re-classification system. The change of basic unit makes the accuracy higher, but this change was not used in the field because the frontier of the sub-compartment does not exist.

The length of both road and river extracted from Landsat TM was less than that in the forest inventory. The fact results from that Landsat TM only explains the wide road and river and the narrow road and river were neglected. The slope was a key factor resulting in the change. However, there was a slope uncertainty derived from DEMs at different resolution levels (Tang *et al.* 2003; Shao *et al.* 2004), and the slope from different data also indicated some differences based on DEM and forest inventory information. For example, in the Jinsong forest farm (Fig. 2), the area with slope≥30° is 1 250 m^2 based on the DEM with a scale of 1:100,000 and a spatial resolution of 25 m, the chosen sub-compartment and compartment was 36.5 hm^2 and 267.77 hm^2, respectively; the area with slope≥30° is 221 900 m^2 based on the DEM with a scale of 1:50 000 and a spatial resolution of 10 m, the chosen sub-compartment and compartment is 1,106.46 $hm^2$and 4 859.79 hm^2, respectively; based on the forest inventory, the area with slope≥30° including 5 sub-compartments is 34.91 hm^2, the chosen compartment covered 1 063.30 hm^2. The data accuracy, data resource and basic unit have an important effect on the classification system.

The GIS techniques are effective to classify and map forest management types. The manual operations have inevitable human errors, which may diminish the repeatability among different users. The applications of GIS method can not only avoid human errors but also take advantage of the statistics such as computing the area and patch number of each management type. In the re-classification system, the area of every category is small and the number is too big, the result makes the management different in fact.

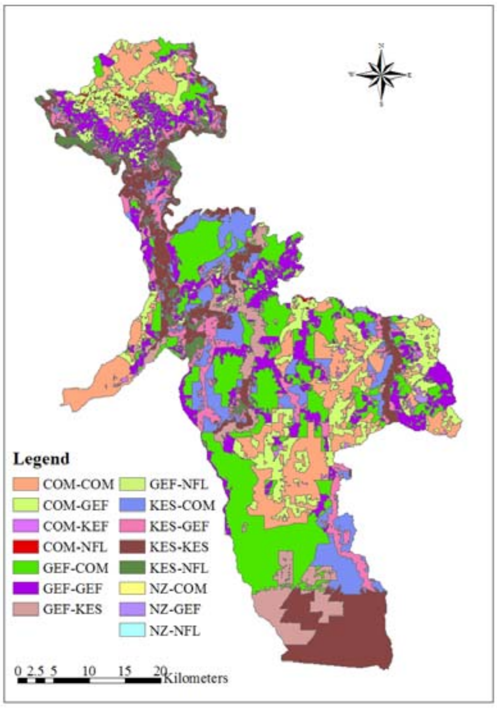

Fig. 1 The comparison between the manually made forest management type classification by the local Forestry Bureau and the re-classified system based on GIS (COM-COM showed that the COM in the manually made forest management type classification by the local Forestry Bureau was converted into COM in the re-classified system based on GIS, others accorded with this rule)

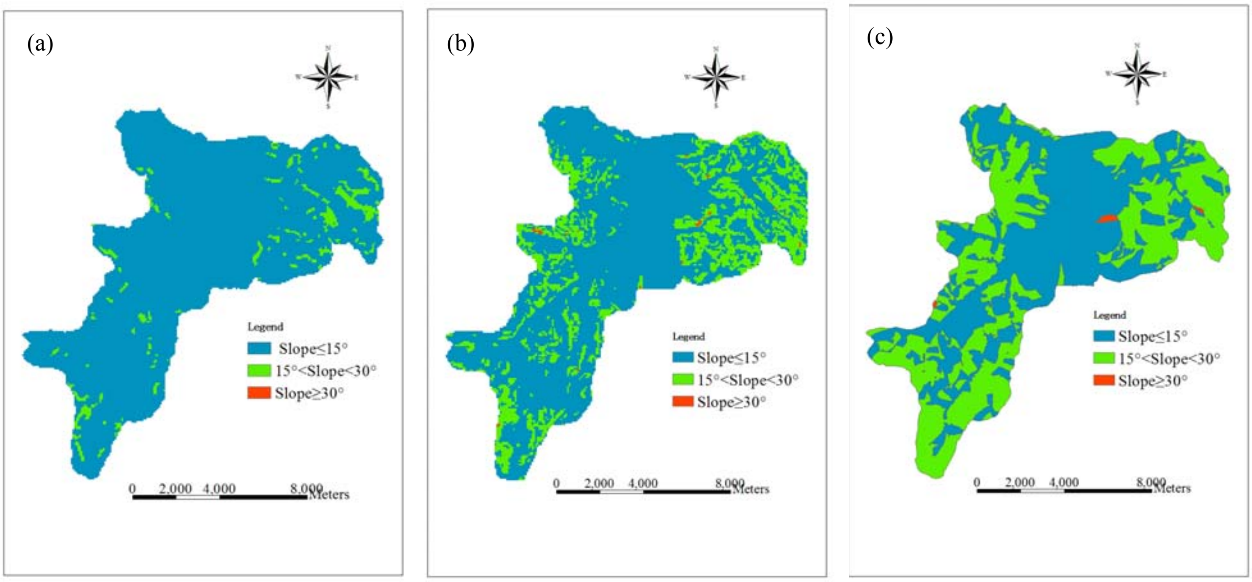

Fig. 2 Slope uncertainty with different data from Jinsong farm ((a) with DEM of 1:100000 and 25 -m cell as the basic unit, (b) with DEM of 1:50000 and 10 -m cell as the basic unit, (c) with forest inventory)

Conclusions

A two-hierarchy system was applied in the GIS-based forest management type classification system in Baihe Forestry Bureau. The top-level classes were composed of the non-forest and forest. Over 96% of land area was forest, which was further divided into KES, GES, and COM. The non-productive forest was the major body. There were obvious differences between manually made and GIS classifying forest management type

classification system. Integrating the forest inventory data with other data such as satellite images, DEM and so on was definitely necessary in classifying the forests into appropriate management types and the GIS technology was effective to classify and map forest management types. Results obtained in this study were preliminary and multi-hierarchy system should be applied in further study.

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